Mapping Heavy Metal Enrichment in Surface Sediments of Catchments Areas of Davao City and Samal Island (IGaCoS): Basis for Resource Management

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Abstract. Heavy metals enter riverine and estuarine environments through both natural processes and human activities, with sediments acting as primary sinks where these contaminants accumulate over time. Their presence at varying depths raises concerns about pollution sources, concentration levels, and spatial patterns. This study presents a spatial assessment of selected heavy metals (Cd, Cu, Fe, Pb, Mn, As, Hg, Cr, and Zn) in surface and bottom sediments collected from five sampling sites across the ecological catchments of Davao City and the Island Garden City of Samal (IGaCoS), covering approximately 354 km². Metal concentrations were analyzed using Flame Atomic Absorption Spectrometry (FAAS). Results indicate higher levels of As (0.103 mg/kg), Cu (195.11 mg/kg), Cr (69.92 mg/kg), Pb (27.59 mg/kg), Zn (170.0 mg/kg), and Mn (373.78 mg/kg) in industrial zones of Davao City compared to residential, riverine, and recreational areas. Spatial distribution patterns suggest that human activities are the dominant source of metal enrichment in these environments. The findings provide baseline data that can support water resource management planning and help address potential ecological risks within the Davao–IGaCoS catchment system.

1 Introduction

The presence of heavy metals in sediments has long been recognized as a significant issue affecting aquatic ecosystems and human health. These contaminants are characterized by their persistence, toxicity, and tendency to accumulate in the environment, making them a serious concern due to their potential for bioaccumulation [1]. Anthropogenic activities play a major role in introducing heavy metals into aquatic systems, increasing their overall concentration in these environments. Sediments act as important reservoirs for these metals, often containing the majority of the total metal load in aquatic systems, which can degrade

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habitat quality, limit the use of water resources such as drinking water, and negatively impact aquatic organisms [2].

Sediment pollution has been identified as a major factor influencing water quality in many regions, including over 100,000 miles of monitored bodies of water (rivers and streams) in the United States [3]. In the Philippines, numerous studies have also examined heavy metal contamination across different catchments. In toxicology, these elements Cd, Cu, Fe, Pb, Mn, As, Hg, Cr, and Zn) are widely recognized and documented for their harmful effects on living organisms [4]. These metals commonly originate from domestic waste, industrial effluents, agricultural runoff, and rapid urban and industrial development. Over time, such inputs accumulate in estuarine environments and are often discharged into surrounding water bodies without adequate treatment [5].

Rivers serve as major pathways for transporting contaminants into estuarine systems, where freshwater mixes with seawater. These transitional environments support diverse biological communities, including fish and invertebrates that are important for ecological balance and fisheries. However, they are particularly vulnerable to pollution due to continuous inputs from upstream sources. Surface runoff further contributes to the movement of land-based pollutants into coastal zones, influencing the chemical composition of these ecosystems. Once introduced into the water column, heavy metals tend to bind with suspended particles and eventually settle into sediments, where they can accumulate and enter the food web through biomagnification processes.

Elevated concentrations of heavy metals can have toxic effects on aquatic organisms [7]. Sediments favor the retention and accumulation of these contaminants, making them both a long-term storage site and a potential secondary source of pollution. For this reason, sediments are widely used as indicators of environmental quality. Their ability to retain higher concentrations of contaminants compared to water makes them useful for assessing spatial and temporal trends in pollution levels [8].

The results of this study aim to exhibit science-based policies and guidelines related to the management, transport, and disposal of hazardous heavy metals in urban catchments. Ultimately, the findings are expected to support the strengthening and implementation of environmental protection measures at the local and national levels.

2 Materials and Methods

2.1. Materials and Sampling Sites

For both cities, samples were taken as representative of a wide area of 354 km^2 (see figure 1). Heavy metals urban catchments were classified into five sites, clustered as: High Density Industrial Zones (Davao City); typical estuary environment in Davao River (Davao City); typical estuary environment in Talomo River (Davao City); High density residential zone (Babak, IGACOS); and Recreational site (Beach Resort Talikud, IGACOS).

Fig. 1. Sampling Sites Showing Urban Catchment

Surface and bottom sediment samples were obtained using a stainless steel sampler in accordance with Environmental Protection Agency (EPA) guidelines [9]. Bottom sediments were collected at depths ranging from 60 to 100 cm. Sampling was conducted on a quarterly basis throughout the year, representing four seasonal periods, and was performed during low tide under favorable weather conditions.

2.2. Methods

After collection, collected specimen were properly stored in resealable plastic containers and transported to the testing facility for further processing. Sample specimen were air-dried, sieved, and subjected to acid digestion prior to elemental determination using Flame Atomic Absorption Spectrometry (Perkin Elmer 900F AAS). Spatial analysis and pollution assessment of heavy metals in the urban catchments were performed using several indices, including the Index of Geoaccumulation coded as Igeo, Contamination Factor coded as Cf, Potential Ecological Risk Index coded as RI, and correlation matrix analysis [10].

The geoaccumulation index (Igeo) was determined by comparing measured metal concentrations with their corresponding pre-industrial background values in bottom sediments, as expressed by:

$$Igeo = \log_2 C_n / 1.5 B_n \qquad \text{(Equation 1)}$$

where Cn represents the measured level of a given element, and Bn corresponds to its natural background level. The classification scheme for Igeo values, which ranges from unpolluted to extremely contaminated conditions, is presented in Table 1.

Table 1. Index of geoaccumulation (I_{geo}) for contamination levels

Class	Computed value	Contamination level
0	$I_{geo} \leq 0$	No contamination / Background level
1	$0 < I_{geo} < 1$	Slightly contaminated / Low-level contamination
2	$1 < I_{geo} < 2$	Moderate contamination
3	$2 < I_{geo} < 3$	Moderate to high contamination

4	$3 < I_{geo} < 4$	High contamination
5	$4 < I_{geo} < 5$	High to very high contamination
6	$5 < I_{geo}$	Severe contamination / Very high contamination

The contamination factor (C^i_f) was calculated using the following relationship:

$$C^i_f = C^i_o / C^i_n \qquad \text{(Equation 2)}$$

Where C^i_o denotes the average concentration of each metal obtained from the sampling sites, and C^i_n represents the corresponding pre-industrial concentration in bottom sediments. The classification of contamination levels based on Cf values is summarized in Table 2.

Contamination factor (C^i_f) was carried out using the formula:

$$C^i_f = C^i_o / C^i_n \qquad \text{(Equation 2)}$$

Where C^i_o epresents the average concentration of metals across the sampling sites, while C^i_n refers to the corresponding pre-industrial background concentration of each metal in bottom sediments.

Table 2. Different contamination factor (C^i_f)

C^i_f **value**	**Contamination level**
<1	Minimal metal deposition
1 – 3	Intermediate metal deposition
3 – 6	Elevated metal deposition
≥6	Severe metal deposition

Heavy metal enrichment in different urban catchments was further evaluated using the Potential Ecological Risk Index (RI), an approach derived from sediment-based assessment methods and calculated as follows:

$$Cf^i = CR^i / CB^i$$

$$Er^i = Tr^i \times Cf^i$$

$$\text{RI} = \sum_{i=1}^{m} E_r^i \qquad \text{(Equation 3)}$$

The potential ecological risk index (RI) refers to total posed by all analyzed heavy metals. The term E^i_r idenotes the individual ecological risk associated with a specific metal, while T^i_r efers to its toxic-response factor. The contamination factor is expressed as C^i_f whereas, C^i_R C^i_B correspond to the measured concentration of metals in sediments and their respective pre-industrial background values. The RI follows the Hakanson method and provides an integrated assessment of ecological risk from multiple metals. Risk levels are classified as follows: Computed RI with values less than 150 indicates low ecological risk; RI between 150 to 300 is interpreted as moderate ecological risk; Computed RI of more than 300 but less 600 indicates considerable ecological risk; and RI equal to or greater than 600 represents very high ecological risk.

Pearson correlation analysis was also applied to evaluate relationships among the measured variables. Computation for statistical significance was set at p value of les than or equal to 0.05 and 0.01. To interpret the data, Pearson correlation coefficient (r) was integrated to determine strong positive relationships between metal pairs, which may suggest common sources, similar transport pathways, and comparable accumulation behavior within the sediments.

3 Results and Discussion

Figure 2 presents the overall concentrations of heavy metals across the five urban catchments. The results indicate a clear indication of continued anthropogenic activities on the accumulation of heavy metals in surface soil samples, following the order: Fe > Mn > Zn > Cr > Cu > Pb > Cd > As > Hg in Davao City and IGaCoS.

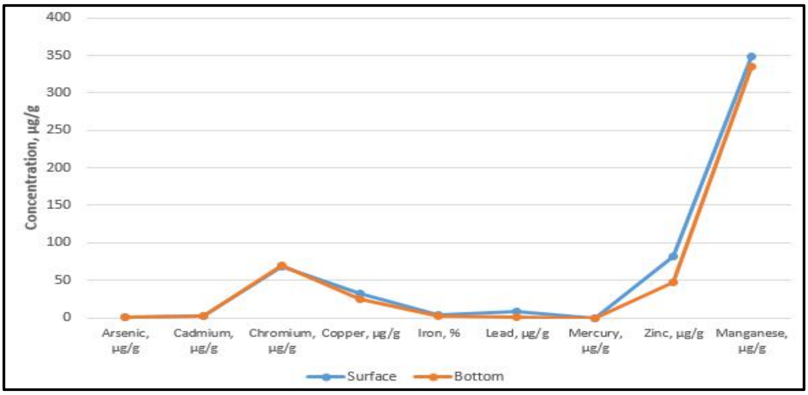

Fig. 2. Mean Profile of Heavy Metals from Five Samplings Sites in Surface and Bottom Sediments

Elevated concentrations of As, Cu, Cr, Pb, Zn, and Mn were observed in the high-density industrial area, with mean values of 0.103, 195.11, 69.92, 27.59, 170.0, and 373.78, respectively.Accumulation of Cd was found at urban catchments of high residential area, near shore river catchment and recreational areas. Cd concentration in a high degree can be attributed to man-made routes of phosphate fertilizers and sewage sludge [11]. Overall, enriched metal concentrations observed in surface sediments could be controlled by lithogenic or anthropogenic.

Meanwhile, an index of geo-accumulation of heavy metals, as shown in Table 3, of five urban catchments revealed Class 0 and Class 2 (i.e., unpolluted and moderately polluted). Most urban catchments are designated Class 0 (i.e., unpolluted), except in High Density Industrial Zone and High Residential Area. The greatest contribution to Class 2 and 1 resulted from substantial Pb enrichment in both regions.

Table 3. Index of geoaccumulation (Igeo) for contamination levels in Sediments Along Davao City and IGACOS

	INDEX OF GEOACCUMULATION				
Parameters	**Site A**	**Site B**	**Site C**	**Site D**	**Site E**
Arsenic, µg/g	≤ 0	≤ 0	≤ 0	≤ 0	≤ 0

Cadmium, μg/g	≤ 0	0.00	0.00	0.00	0.00
Chromium, μg/g	0.00	0.00	0.00	0.00	0.00
Copper, μg/g	0.00	0.00	0.00	0.00	0.00
Iron, %	0.00	≤ 0	0.00	0.00	≤ 0
Lead, μg/g	>5*	1	≤ 0	≤ 0	≤ 0
Mercury, μg/g	≤ 0	≤ 0	≤ 0	≤ 0	≤ 0
Zinc, μg/g	0.00	0.00	0.00	0.00	0.00
Manganese, μg/g	0.00	0.00	0.00	0.00	0.00

Legend: Site A- High Density Industrial Zone;
Site B - High Residential Area;
Site C - Near shore River Catchment (Davao Coast);
Site D: Near shore River Catchment (Davao Coast); and
Site E: Recreational Areas (IGACOS)

The contamination factors of Cd, Cr, Cu, Pb and Zinc (Table 4) were relatively high in the urban catchments where high industrial zone, high residential area and typical estuarine classes were found, which generally fall between moderate and heavy levels of contamination. Based on these results, Pb > Zn > Cu > Cd > Cr is defined as level of metal enrichment.

Table 4. Contamination Factor (Cfi) of Sediments Along Davao City and IGACOS

	CONTAMINATION FACTOR OF CONTAMINANTS				
Test Parameter	**Site A**	**Site B**	**Site C**	**Site D**	**Site E**
Arsenic, μg/g	0.8	1.0	1.0	1.0	1.0
Cadmium, μg/g	1.0	1.0	1.0	**1.5**	1.0
Chromium, μg/g	1.0	**1.2**	0.9	**1.2**	0.9
Copper, μg/g	**1.6***	**1.5**	0.9	1.1	1.0
Iron, %	1.0	1.2	1.1	1.6	0.7
Lead, μg/g	**>6***	**4.1***	1.0	1.0	1.0
Mercury, μg/g	1.0	1.0	1.0	1.0	1.0
Zinc, μg/g	**3.0***	1.2	1.1	1.7	1.0
Manganese, μg/g	0.8	1.0	1.0	1.4	0.9

The potential ecological risk index (RI) values presented in the table were generally below 150, indicating low ecological risk in urban catchments such as high residential areas, nearshore river zones, and recreational sites. In contrast, the industrial zone exhibited a markedly elevated RI value of 781 (RI > 600), which corresponds to a very high ecological risk classification. This suggests that heavy metal contamination in this area poses significant environmental concern. Among the analyzed elements, lead (Pb) was identified as the primary contributor to the overall RI due to its high toxicity.

Table 5 Potential Ecological Risk Index (RI) of Heavy Metals along Davao City and IGACOS

Sampling Sites	**Individual Heavy Metals**							**(Multi-Metal) RI**
	As	**Cd**	**Cr**	**Cu**	**Pb**	**Hg**	**Zn**	

Sampling Point A	8.2	30.2	1.9	7.9	689.9	40.0	3.0	**781**
Sampling Point B	10.0	30.7	2.3	7.3	20.7	40.0	1.2	112
Sampling Point C	10.0	29.3	1.7	4.7	5.0	40.0	1.1	92
Sampling Point D	10	46.4	2.4	5.5	5.0	40.0	1.7	111
Sampling Point E	10	30.5	1.9	4.8	5.0	40.0	1.0	93

Pearson's product–moment correlation analysis demonstrated strong and statistically significant relationships (based on R values) among several metal pairs, including As and Cr (0.954), As and Fe (0.913), As and Pb (0.913), As and Cu (0.878), Cr and Cu (0.858), Pb and Cu (0.927), and Fe and Zn (0.914). These strong positive correlations suggest that the metals across the five urban catchments may originate from similar sources or shared input pathways. Furthermore, such relationships indicate that these elements likely undergo comparable transport processes and accumulation patterns within the sediment environment.

Table 6. Pearson Correlation Matric of Heavy metals of sediments samples

Parameters	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Zn**	**Mn**
Arsenic	1.0*							
Cadmium	-0.538	1.0*						
Chromium	**0.954***	-0.729	1.0*					
Copper	**0.878***	-0.726	**0.858***	1.0*				
Iron	**0.913***	-0.555	0.144	0.135	1.0*			
Lead	**0.913***	-0.457	**0.806***	0.927*	-0.220	1.0*		
Zinc	0.784	-0.712	0.759	0.225	0.269	0.859	1.0*	
Manganese	0.044	-0.733	0.304	0.171	**0.914**	-0.186	0.230	1.0*

***Correlation is significant at 0.05 level of significance**

4. Conclusions

This study focused on selected urban, industrial, and recreational catchments in Davao City and IGaCoS. Despite their geographic separation, these areas share similar lithological characteristics, with sandy formations comprising more than 90% of the surface. Based on the geoaccumulation index, lead (Pb) exhibited moderate contamination levels, particularly in the high-density industrial zone and high residential areas. The contamination factor analysis further indicated notable enrichment of Cd, Cr, Cu, Pb, and Zn in industrial, residential, and estuarine catchments, with contamination levels ranging from moderate to considerable. A markedly elevated potential ecological risk index (RI) was observed in the industrial zone, largely driven by the high contribution of Pb. Correlation analysis using Pearson's product–moment method showed strong and statistically significant relationships among several metal pairs, suggesting that these contaminants likely originate from common sources and follow similar transport and deposition processes. Overall, the findings highlight the significant influence of anthropogenic activities on heavy metal accumulation in sediments. These results underscore the need for targeted management strategies and remediation efforts to reduce environmental risks and protect aquatic ecosystems in the study area.

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